

(18) 19
USAAVRADCOM TR-81-D-10



LEVEL
(12)

ADA101603

(2) MM&T - LOW COST PRODUCTION/INSTALLATION OF
URETHANE LEADING EDGE GUARDS ON ROTOR BLADES.

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DTIC
JUL 17 1981

(11) Jun 1981

(12) (13) (14) R-16274

(9) Final Report, (redacted) 23 Aug (redacted) / 9 December 1980

(15) DARKSI-29-C-0024

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Prepared for

U. S. ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
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St. Louis, Mo 63120

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U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report was prepared by Kaman Aerospace Corporation under Contract DAAK51-79-C-0024. The report documents the manufacturer and literature survey conducted to obtain suitable erosion guard materials; the flow, bonding and temperature characteristics of the selected materials; and demonstration of the feasibility of the boot molding process on a four-foot section of blade. Results of this program can be used as a data base for a research and development program aimed at the forming/bonding of polyurethane leading edge guards for helicopters.

Mr. Drew G. Orlino, Structures Technical Area, Aeronautical Technology Division, served as project engineer on this effort.

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1. REPORT NUMBER USAARVADCOM TR 81-D-10	2. GOVT ACCESSION NO. FD-A101603	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MM&T-LOW COST PRODUCTION/INSTALLATION OF URETHANE LEADING EDGE GUARDS ON ROTOR BLADES	5. TYPE OF REPORT & PERIOD COVERED Final Report Aug 1979 - Dec 1980	
7. AUTHOR(s) M. L. White A. L. Belbruno	6. PERFORMING ORG. REPORT NUMBER R-1627A	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Kaman Aerospace Corporation Old Windsor Road Bloomfield, CT 06002	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PWD A1-90-S7297-901K	
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Aviation Research & Development Command 4300 Goodfellow Blvd St Louis, MO 63120	12. REPORT DATE June 1981	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM) Fort Eustis, VA 23604	13. NUMBER OF PAGES 56	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.	15. SECURITY CLASS. (of this report) Unclassified	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) HELICOPTERS PROTECTIVE COVERINGS BONDING ROTOR BLADES URETHANES FABRICATION LEADING EDGES MANUFACTURING METHODS EROSION RESISTANCE MOLDING MATERIALS PROTECTION MOLDING TECHNIQUES		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This program to develop a process for a low-cost production/installation of urethane leading edge guards for rotor blades was to consist of three tasks as follows: <ul style="list-style-type: none"> • Task I - Manufacturing Process Identification. <ul style="list-style-type: none"> (a) Conduct a survey of manufacturers and literature for suitable erosion guard materials. (b) Determine flow, bonding, and temperature characteristics of the selected material. 		

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20. (Continued)

- c. Demonstrate the feasibility of the process of molding a boot on a 4-foot section of blade.
- Task II - Tool Design and Fabrication •
From the results obtained in the molding phase of Task I, refine the tool concept and design and fabricate a tool to mold an erosion boot on a full-length blade.
- Task III - Fabrication Process Demonstration,
Using the experience gained in Task I and the tool fabricated in Task II, form, bond, and inspect four full-scale leading edge erosion boots. Analyze and compare costs to current production process and prepare manufacturing work instructions. ~~✓~~

The first two phases of Task I were completed, but problems were encountered in the molding portion of the third phase which were not completely overcome. In this phase, a prototype mold was designed and fabricated to match the contours of the outboard 48 inches of the blade leading edge. In trying to mold a boot to a blade section in this mold, air bubbles occurred within the urethane. After 26 runs, the air bubbles had been reduced to pinhead size, but the extra operations necessary to achieve even this improvement added to process costs.

The simple basic process originally envisioned and demonstrated on small (.3 inch long) coupon panels is not suitable for full-scale in-place molding of leading edge guards with this material. While alternate materials and/or tooling concepts might prove satisfactory, the research and development required was beyond the scope and funding limitations of the contract. The program was therefore terminated before completion.

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PREFACE

The work reported herein was performed under Contract DAAK51-79-C-0024, Low Cost Production/Installation of Urethane Leading Edge Guards on Rotor Blades, for the Applied Technology Laboratory, Fort Eustis, Virginia. Mr. Drew Orlino of the Applied Technology Laboratory has been Program Monitor.

This effort was carried on by Kaman Aerospace Corporation, Bloomfield, Connecticut for the period 23 August 1979 through 9 December 1980. At Kaman Aerospace Corporation, Mr. M.L. White was Program Manager and Mr. A.L. Belbruno was Deputy Program Manager.

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Rotar Blade	
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INTRODUCTION

This program was awarded to Kaman Aerospace Corporation by the Applied Technology Laboratory at Fort Eustis, Virginia to establish an improved manufacturing technique for the fabrication and installation of the leading edge erosion guard on the Army's AH-1Q/S composite improved main rotor blade (IMRB), seen in Figure 1. This blade was developed and is being manufactured by Kaman.

At present, the erosion guard for the blade is a thermoplastic polyurethane material which covers the outer 88 percent, approximately 185 inches, of the blade leading edge. This guard is autoclave molded by a vendor by laminating thin sheets of the material to obtain a thickness of .10 inch in the center along the full length and tapering to a feather edge along both trailing edges. When assembling it to the blade, the mating surfaces of the boot and spar are prepared and the boot is then bonded to the blade with epoxy adhesive under a vacuum blanket.

This MM&T program was intended to establish and demonstrate a cocuring procedure whereby the leading edge erosion guard would be formed, tapered, and bonded to the properly prepared spar surface in a heat-molding operation in a special fixture. This should result in a cost reduction because of the elimination of the purchased leading edge boot which is specially shaped and formed to final dimensions by a vendor, and the reduction of operations when being assembled to the blade such as adhesive application, bagging, and squeegeeing excess resin.

The proposed process is for a urethane sheet to be positioned over the properly prepared surface of the spar, which has received a coating of adhesive. The blade assembly is then placed into a specially fabricated contoured mold which has the capability of being heated and cooled. As the temperature is increased, the material, being a thermoplastic, is softened to its flow point and the blade spar is forced into position. The urethane flows and tapers into a feather edge while adhering to the spar. After cooling, the blade is removed and cleaned up with minimum effort. Upon

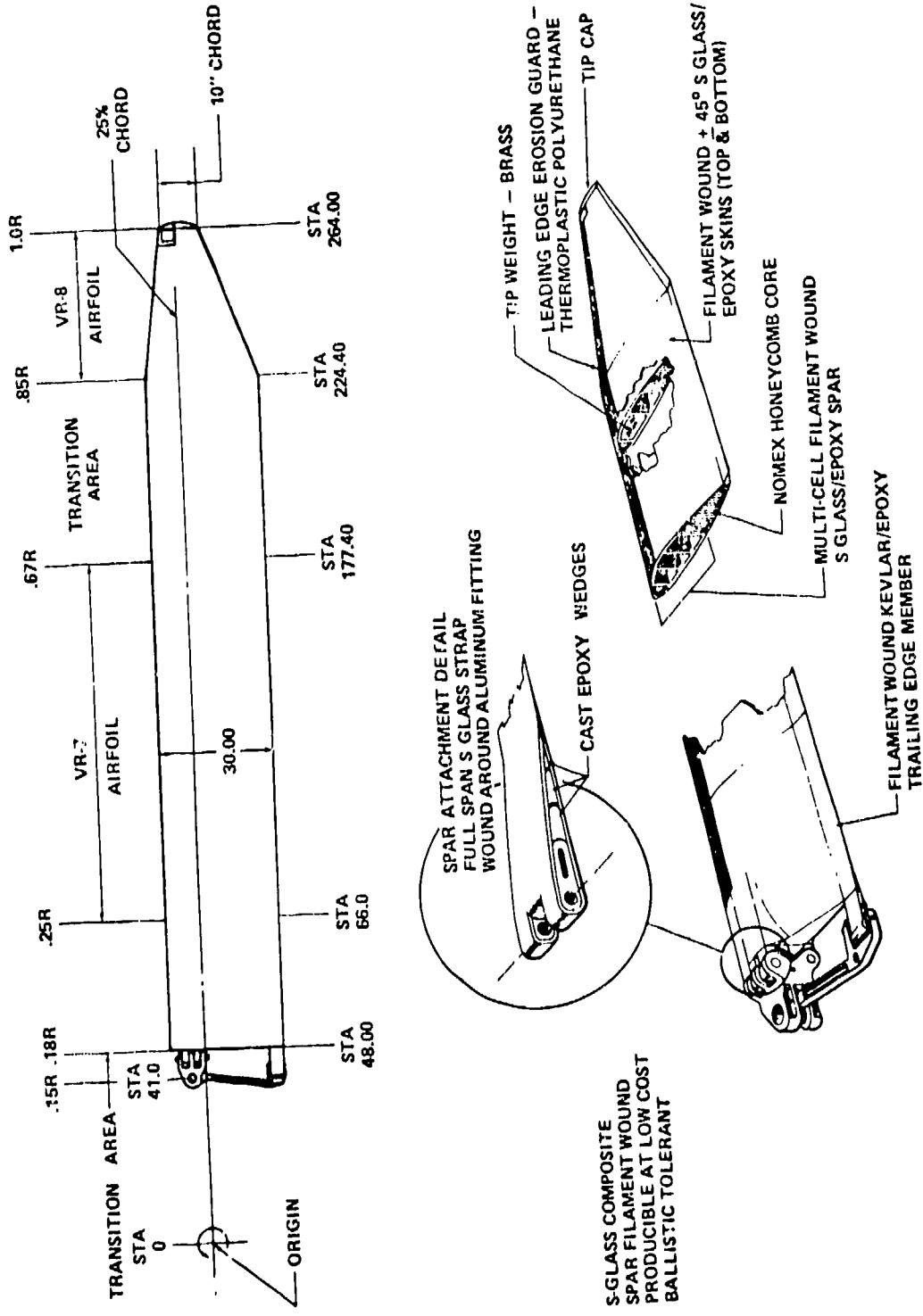


Figure 1. AH-1Q/S blade configuration.

completion of the program, the materials, process and quality requirements were to be issued as standard Kaman documents.

PROGRAM PLAN

This program, as outlined, was to be accomplished in three tasks:

- Task I - Manufacturing Process Identification

Review current processes for forming and bonding nonmetallic leading edge guards on airfoil surfaces, including rotor blades, wings, and fins. Select candidate material systems possessing characteristics equal to or better than those of the material now in use on the IMRB. For each system, evaluate candidate molding and bonding processes on coupon specimens that simulate the blade leading edge. Parameters including, but not limited to, cure temperature, pressure, time, and material type shall be varied and evaluated during the process evaluation. Destructive and nondestructive inspection shall be performed on the coupons to determine quality and thickness conformance of the formed erosion guard and the adhesive layer between the guard and simulated blade surface. At the completion of this task, the Contractor would brief the Contracting Officer on his selected manufacturing process for forming and bonding the erosion guard to the blade in one continuous operation, with supporting rationale for the selection.

- Task II - Tooling Design and Fabrication

Upon approval from the Contracting Officer of the system selected in Task I, define tooling requirements for the selected manufacturing process. Design and manufacture a tool for demonstrating the selected manufacturing process on full-scale blades. The tool would be of sufficient quality to enable demonstration on 12 blades.

- Task III - Fabrication Process Demonstration
 - a. Using the selected manufacturing process with the tooling fabricated in Task II, fabricate and install the leading edge erosion guards on two full-scale AH-1Q blades. Remove the erosion guards and again fabricate and install the leading edge erosion guards on the two blades. Inspect all the guards against established standards.
 - b. Based on recorded man-hours and material costs for each blade, project cumulative average production costs for this operation for a production buy of 500, 1000, and 2000 blades, and perform an economic analysis comparing the new and old manufacturing method. Identify any additional requirements which would be necessary in order to incorporate the developed leading edge guard manufacturing technique into the AH-1Q IMRB production.
 - c. Prepare manufacturing instructions for application of the process in blade production.

PROGRAM IMPLEMENTATION

TASK I - PROCESS IDENTIFICATION

Manufacturer and Literature Survey

The primary leading edge guard material candidate is that used in the current leading edge guard, Estane 82-083, manufactured by B.F. Goodrich Company. It has been qualified for use after being extensively tested for rain and sand erosion and was used on rotor blades for the Kaman HH43B and for leading edges for all servo-flaps for the SH-2 rotor blades currently in service. Successful development of the proposed manufacturing process with the Estane material would permit production application without significant additional requalification. It was considered that selection of another material would require sand and rain erosion testing to the original blade design criteria. For this reason, it was decided that other candidate materials would be identified by literature study and

vendor contacts. They would be laboratory evaluated if the Estane failed to exhibit satisfactory characteristics for the proposed process.

The findings of the survey of urethane sheet materials which are potential candidates are discussed herein.

The basic resin suppliers such as DuPont, Upjohn and Uniroyal supply the urethane in pellet form to processors. They, in turn, manufacture the thermoplastic sheets to various thicknesses and widths in roll form or the thermoset products such as castable liquids or B-staged sheets which are moldable, but once cured are not readily reformable. Most of the companies that make thermoplastic sheeting supply it in thicknesses only to approximately 20 mils.

For this program, the Estane was furnished in sheets of constant cross section to a thickness of .125 inch and then molded to a thickness of .10 inch on the blade.

In addition to the B.F. Goodrich Company, two other suppliers were found who can furnish a sheet material to the thickness required. One commercially available sheet urethane which was given a cursory examination was found to be harder and stiffer and had a much higher flow temperature than the currently used Estane which is compounded specially for aerospace use.

Specially compounded neoprene sheeting and sprayable neoprene to Government specification have been used on wing, fin, rotor blade, and radome surfaces. The neoprene sheeting has been bonded in place either by contact rubber base adhesives or certain types of epoxies. The sprayable material is supplied in kit form with a primer. However, comparative testing has indicated that urethanes are superior.

Flow, Bonding, and Temperature Characteristics

Adhesive Evaluation. Exploratory adhesive evaluation testing was performed prior to the fabrication of specimens to be used in the actual test program. From these results, it was determined that satisfactory adhesion could be achieved with a 20% solution adhesive, or tie-coat, of Estane/MEK (Methyl-Ethyl-Ketone), which is brushed on the fiberglass surface and allowed to dry.

The design of the blade calls for a spray coating of a material referred to as Electrodag +502 under the boot. These adhesive evaluation results indicated that the peel failures occur in the DAG coating.

Test specimens were fabricated using fiberglass panels approximately 3 inches wide and 9 inches long to which Estane was bonded. The fiberglass surfaces were abraded with 240 grit emery paper and solvent wiped with MEK prior to the application of adhesive. The adhesive systems were as follows:

1. Control - no adhesive.
2. Hysol 9620 adhesive.
3. 10% Estane/MEK solution.
4. 20% Estane/MEK solution.
5. DAG 502 and 20% Estane/MEK solution.
6. DAG 502 and 10% Estane/MEK solution.

The assemblies were placed in the laboratory platen press, heated to either 220°F or 230°F for 1 hour, and compressed to obtain a thickness of .10 inch. After cooling to room temperature, the panels were cut into 1-inch-wide strips and tested for 180-degree peel strength per ASTM D903-49.

Results of the comparative tests are shown in Table 1.

Based on the results of these tests, no further adhesive evaluation was performed. Work was continued with the Estane/MEK tie-coat adhesive

TABLE 1. 180-DEGREE PEEL TEST RESULTS TO EVALUATE ADHESIVE SYSTEMS FOR BONDING ESTANE BOOT MATERIAL

No.	Fiberglass Surface Preparation	Surface Coating	Molding Temp. (°F)	Avg Peel Strength (lbs/in.)	Failure
1	Abrade & MEK solvent wipe	Bare	220	12	Adhesive to glass
2		Hysol EA 9620	220	9-12	
3		10% solids Estane/MEK 2 coats	220	16	
4			220	18-19 16-19	
5		DAG 502 10% Estane/MEK 2 coats	220	15-17 14-16	DAG 502
6	Nylon Peel Ply	DAG 502 10% Estane/MEK 1 coat	230	10	DAG 502
7			230	10	Urethane stretched and failed in tension
8		20% solids Estane/MEK	230	28 26	100% adhesive to glass
9			230	60	90% urethane 10% adhesive to glass
10			230	65 52	80% urethane - 20% adhesive/glass 40% urethane - 60% adhesive/glass
11		DAG 502 20% solids Estane/MEK	230	15	DAG 502

- Notes:
1. Specimens 1 thru 5 and 8 had a reinforcing scrim cloth in the Estane to reduce stretch during testing.
 2. Specimen 7 had no reinforcement in the Estane.
 3. Specimens 6, 9, 10, and 11 had an additional reinforcement of 7-mil nylon molded into the exposed surface to eliminate all stretch during testing.

system for the following reasons:

- The Estane/MEK adhesive is stronger than the Electrodag 502. The critical link in the system is the Dag 502. This is where the failure occurs when the system is subject to peel testing.
- The Estane/MEK adhesive is a low-cost material readily obtained by using the trim material from the Estane boot itself.
- There is no concern for environmental degradation since the adhesive is the same as the base material. No environmental qualification is necessary.

Adhesive Testing Under Selected Parameters. From the preliminary evaluation work, it was determined that pressure varying from 2.0 to 3.5 psi and temperature from 200-240°F were satisfactory for molding the Estane. The test specimens were first made with the 20% Estane/MEK adhesive tie-coat applied by brush, directly over the DAG coating on the fiberglass skins. However, test results for all molding parameters were in the same low range of 5 to 11 pounds per inch of width. Most values were borderline and all failures were in the DAG coating. Subsequent investigation revealed that an extra-heavy coating of DAG had been applied because of a misinterpretation of the graph of conductivity versus ohm meter reading which is used as the application standard.

At this time, it was decided to develop a process that would strengthen the DAG and thus yield higher peel strengths.

Additional investigation indicated that this could be achieved, along with a different mode of failure, by spray-coating epoxy primer over the DAG prior to the application of the adhesive tie-coat. This primer is also used on the afterbody of the blade before painting. Test results showed that peel strengths above 20 pounds per inch of width could be achieved with basic failure between the adhesive and the epoxy primer.

It was decided to use this process for the test specimen program, and also on the blade section when molding in the prototype tool.

Test Matrix. The test program was set up for the specimens to be molded at four different pressures and five different temperatures as per Table 2.

TABLE 2. TEMPERATURE/PRESSURE COMBINATIONS FOR MOLDING PEEL TEST SPECIMENS

Temp (°F)	Pressure (psi)
200	2, 2.5, 3, 3.5
210	Same as above
220	" " "
230	" " "
240	" " "

Test Specimens. All specimens were made with the same surface preparation and process planned for the actual rotor blade spar. A panel of glass fiber impregnated with the same epoxy resin compound used for the spars was precured with a nylon peel ply on one surface. The nylon was removed immediately prior to the application of the DAG to provide a clean, roughened surface. The DAG was spray applied to the required thickness followed by an oven dry. Over this, the epoxy primer was spray applied and allowed to cure overnight. The panel was cut into smaller 3 x 8-inch panels which were brush coated with the Estane/MEK adhesive as needed and allowed to air dry for 2 hours minimum for evaporation of solvent. The Estane was cut into 1 x 8-inch strips and molded to the 3 x 8-inch fiber-glass panels on the surface of a laboratory press preset to the desired temperature, with the proper weight placed on top to maintain constant pressure as the urethane softened and flowed. When molding, the Estane was reinforced by a ply of nylon to eliminate stretching while testing. The material was reduced in thickness by 20%, starting at .10 inch and molding down to .08 inch. Figure 2 illustrates the molding setup. One specimen

was tested for each parameter. Temperatures were monitored on every specimen by thermocouple wire in the joint between Estane and skin. Time to reach the temperature and also bottom to the shims was recorded. Specimens were held at temperature for 10 minutes and then cooled under pressure to 110°F before removal. After removal, the Estane/fiberglass specimens were trimmed to 1 x 8-inch size for testing.

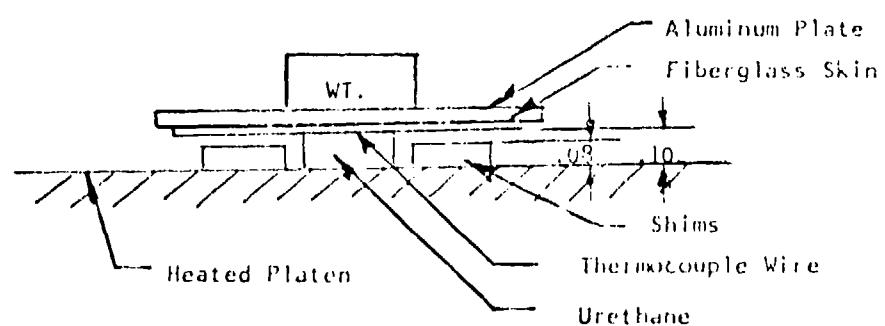


Figure 2. Molding urethane strip to fiberglass under controlled temperature and pressure.

Testing. For testing, the specimens were backed up by a 1/8-inch aluminum strip to reduce deflection and the Estane was peeled away in a Tinius-Olsen tester per ASTM D903-49, as shown in Figure 3.



Figure 3. Method of testing for 180-degree peel strength.

Test Results. Peel test results for the various pressure/temperature combinations are shown in Table 3, and average peel strengths versus temperature and pressure are shown in Table 4.

TABLE 3. FLOW PRESSURE/TEMPERATURE VS. 180-DEGREE PEEL STRENGTH

Pressure (psi)	Temp. (°F)	Minutes to Shims	Minutes to Temp.	Peel Strength (lb/in. Width)	Failure (%)
2	200	10	15	45	100 Adh/Epoxy
	210	7	15	50	100 Adh/Epoxy
	220	5	18	40	90 Adh/Epoxy & 10 Dag
	230	5	18	65	85 Adh/Epoxy & 15 Dag
	240	6	18	45	85 Adh/Epoxy & 15 Dag
2.5	200	8	16	30	80 Adh/Epoxy & 20 Dag
	210	6	15	45	95 Adh/Epoxy & 5 Dag
	220	5	18	50	80 Adh/Epoxy & 20 Dag
	230	5	19	45	95 Adh/Epoxy & 5 Dag
	240	5	19	40	98 Adh/Epoxy & 2 Dag
3	200	9	15	35	80 Adh/Epoxy & 20 Dag
	210	6	16	45	75 Adh/Epoxy & 25 Dag
	220	4	16	60	100 Adh/Epoxy
	230	5	17	45	95 Adh/Epoxy & 5 Dag
	240	4	19	40	95 Adh/Epoxy & 5 Dag
3.5	200	7	14	60	90 Adh/Epoxy & 10 Ureth
	210	6	16	70	100 Adh/Epoxy
	220	5	14	65	100 Adh/Epoxy
	230	4	18	50	100 Adh/Epoxy
	240		20	55	90 Adh/Epoxy & 10 Dag

- Notes:
1. The failure mode was 5-25% in the DAG and the rest was adhesive to epoxy primer.
 2. It is felt that much of the scatter in results was due to occasional separation of the fiberglass panel from the aluminum backing plate.
 3. While the highest average peel strengths were obtained using the 3.5 psi with the various temperatures, the other pressure/temperature combinations all yielded very acceptable peel strengths.

TABLE 4. AVERAGE 180-DEGREE PEEL STRENGTH VS. TEMPERATURE

Temperature (°F)	Molding Pressure (psi)				Peel Strength Average (lb/in. width)
	2	2.5	3	3.5	
200	45	30	35	60	42.5
210	50	45	45	70	52.5
220	40	50	60	65	53.8
230	65	45	45	50	51.3
240	45	40	40	55	45.0

Discussion. As seen from the test results, the temperature/pressure molding cycles are not critical. Since the material is a thermoplastic, the time at temperature only needs to be sufficiently long to permit the flowing urethane to assume the contours within the mold and adhere to the spar surface. After this occurs, it must be cooled before removal.

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When molding, the thickness of the boot must be controlled by stops or shims. Therefore, the molding pressure or force needed to move the blade into position will be dependent upon mold temperature and softness of the urethane.

Tooling

Early planning was that the tool for the full-length blade would be made from either the Versitool tooling process or electroformed nickel, both described below. For the 4-foot prototype mold needed for Task I, the Versitool process was chosen.

This process was developed by Owens Corning Fiberglas Corporation. It employs a thin, approximately .04 inch, tin zinc shell which is flame sprayed on the master model. The exposed side of this shell is then reinforced with

a cast, aluminum-filled epoxy compound. Copper tubing for water heating under pressure and cooling was embedded in the cast back-up within 1/4 inch of the sprayed metal face.

The alternate type of tool under consideration, made from electroformed nickel, is produced by electroplating 1/8 inch of nickel on an epoxy model, tack welding the heating/cooling tubes to the shell, and then electroplating an additional 1/8 inch of nickel to encapsulate the tubes. The mold would incorporate flanges and stiffeners to support it in the tool.

Final selection of the type of mold for the full-length production tool was to be based on a detailed evaluation of the performance of the tool for the process requirements, the heating and cooling rates versus projected requirements, and the estimated tool durability.

Prototype Tool Design and Fabrication

The prototype mold was designed for the outboard end of the blade from Station 212 to Station 262. This is the most difficult area on which to mold a boot, since it extends through the Station 224 area where the sweepback of the leading edge starts and the blade narrows and thins down out to the tip. Also, the tip end contains a 53-pound brass weight counterbalance which affects heat-up.

The leading edge surface of blade S/N 1010 was built up with tooling wax in the area mentioned above to simulate boot thickness. Over this, the female plaster mold seen in Figure 4 was made, and in this, the male epoxy master was made.

Figures 5, 6, 7, and 8 show the mold in the various stages: spraying the metal, locating the tubing, pouring the resin, and curing after pouring. In Figure 7, flexible hoses are seen attached to the copper tubing, through which cooling water is run to control exothermic action of the resin mass.



Figure 4. Female mold made on blade S/N 1010.



Figure 5. Metal spraying the male mandrel.

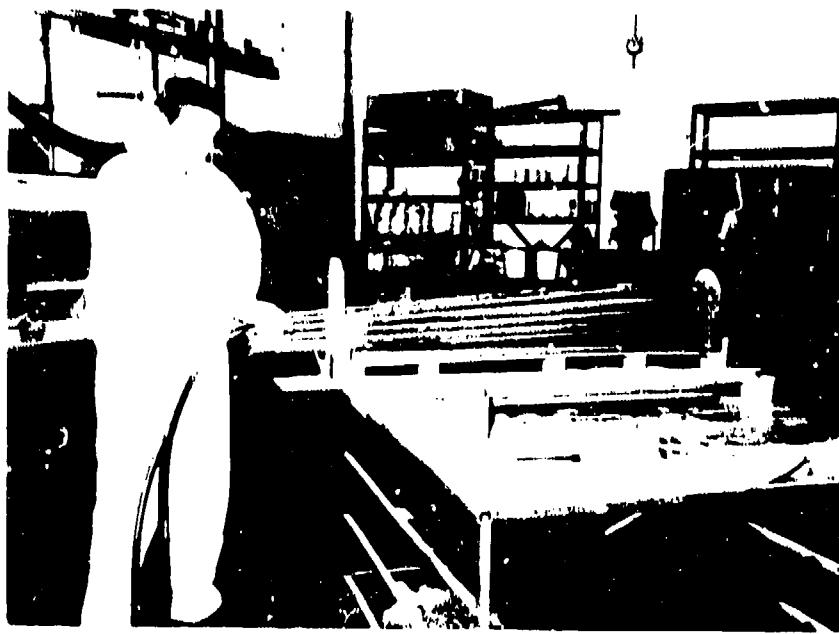


Figure 6. Mandrel with copper tubes in place prior to pouring resin.

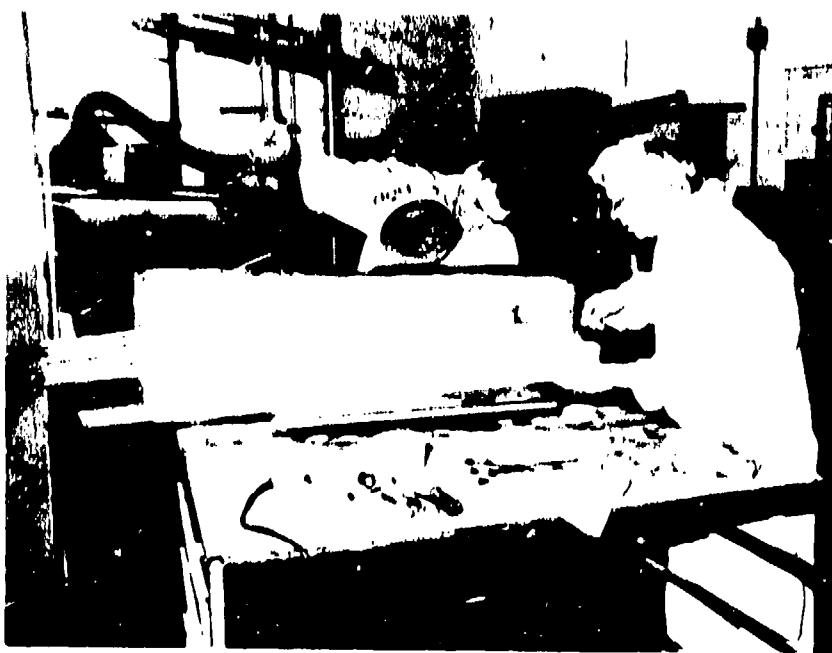


Figure 7. Pouring resin for the mold.

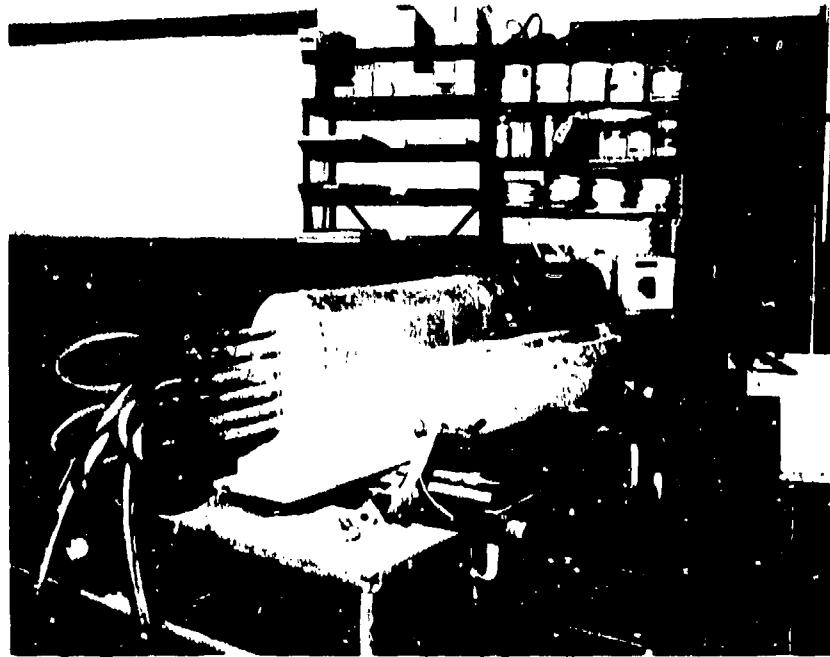


Figure 8. Mold being cured after pouring.

Figures 9 and 10 show the mold after completion and set up on the shop floor. In Figure 10, at the left end of the fixture between the heating/cooling tubes, may be seen the turnbuckle and metal strap that attaches to the extension of the outboard end of the brass weight to pull the blade tip into place. At the inboard end is a yoke arrangement that straddles the blade trailing edge and is used in conjunction with the turnbuckle to force the blade into position. This arrangement is more clearly seen on page 26 of this report.

Although the tubes at both ends of the fixture are seen exposed, they were wrapped with insulation before starting the program for more efficient operation. Water flow at the inlet ends of the tubes is controlled by flow valves.

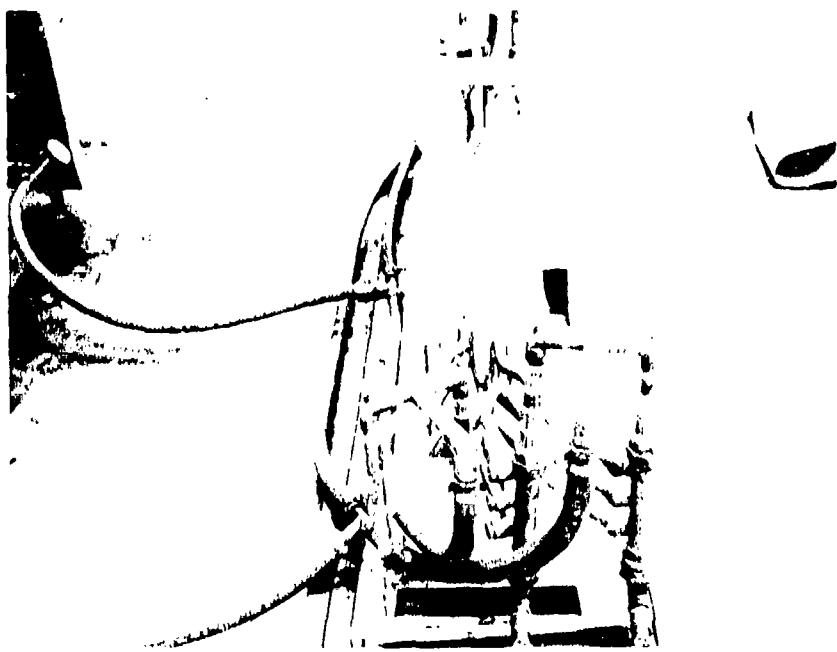


Figure 9. Prototype boot molding fixture.

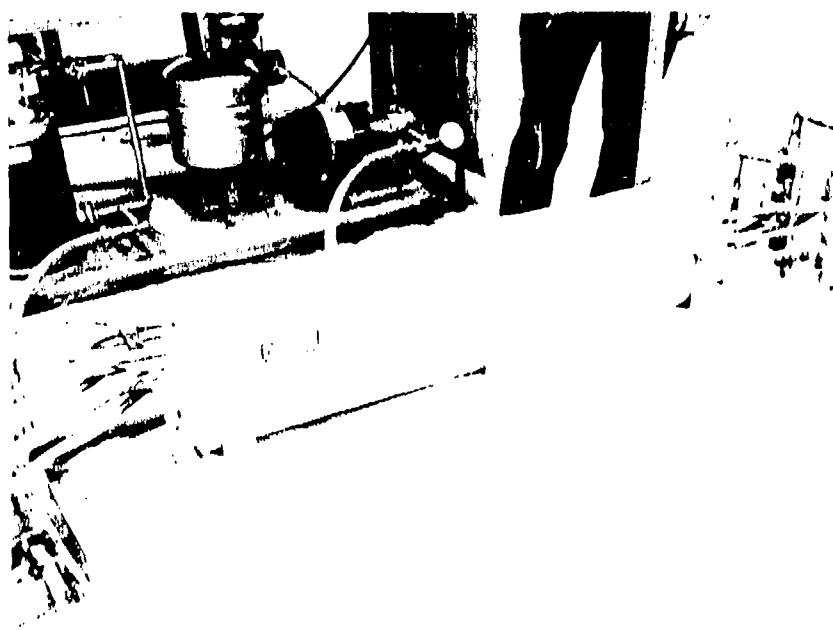


Figure 10. Prototype boot molding fixture - side view.

Figure 11 is a layout and schematic of the heating/cooling unit of the bond fixture.

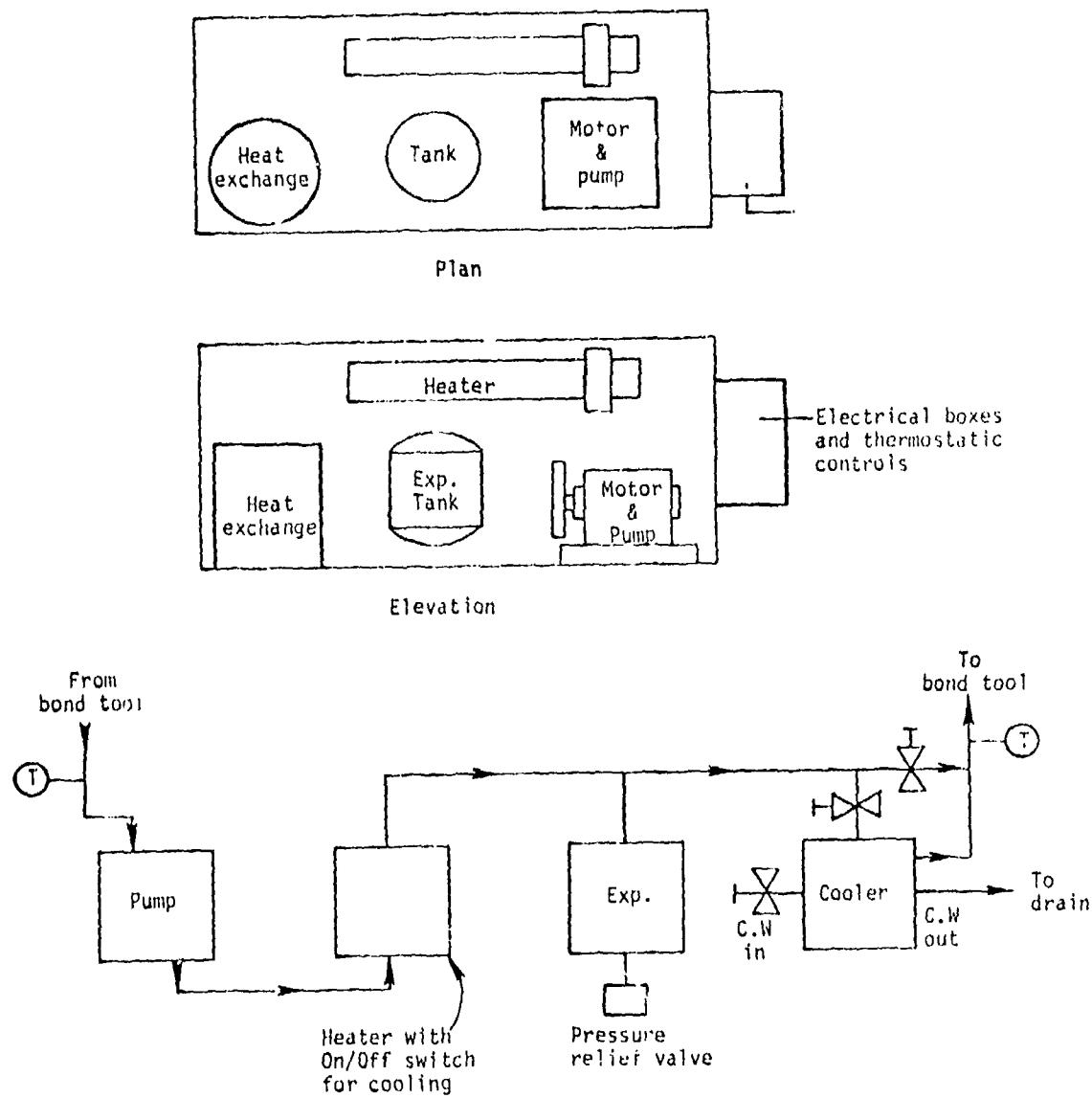


Figure 11. Layout and schematic of heating/cooling unit for boot molding fixture.

Figure 12 shows the assembled unit and figures 13 and 14 show the unit connected to the tool. The unit is completely sealed for pressurization and incorporates pressure relief valves. Thus, hot oil or water under pressure to obtain temperatures above the fluid boiling point at atmospheric pressure may be circulated. In this program, all heating was obtained with pressurized hot water circulated through the copper tubing. To cool the mold, the water is rerouted through the heat exchanger, seen on the left side of the unit, and cooled while being recirculated.

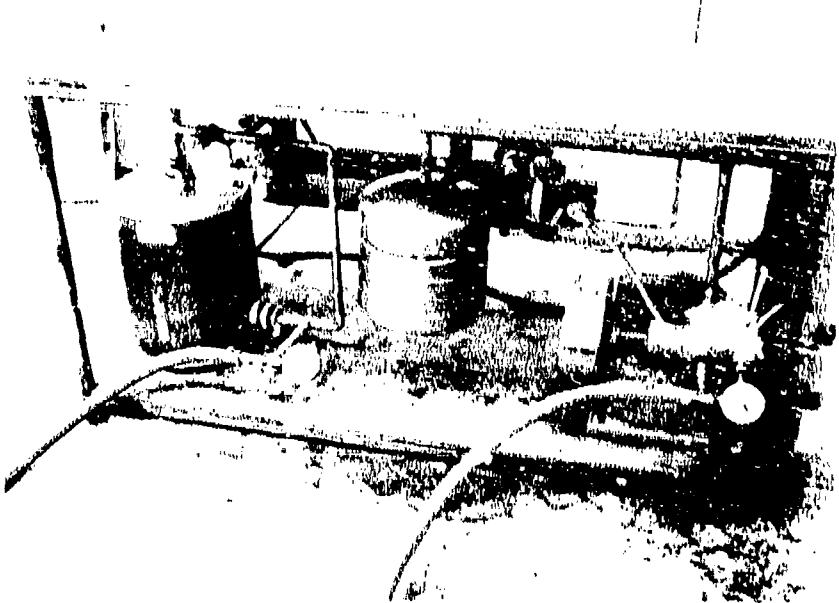


Figure 12. Heating/cooling unit after assembly.

After the first heat survey run, it was found that the mold had developed a crack across both flanges and at two places in the nose. The flange cracks were attributed to the fact that the mold was bolted to the base at both ends, and in trying to expand when heated under restraint, the cracks developed. The cracks in the nose were due to the closeness of the copper heating tubes to the surface. The bolts were removed from the outboard end of the fixture to allow it to expand freely. At the end of the third heat survey, an additional crack had developed in each flange. The cracks in the flanges had extended down into the sides of the molds on the outside

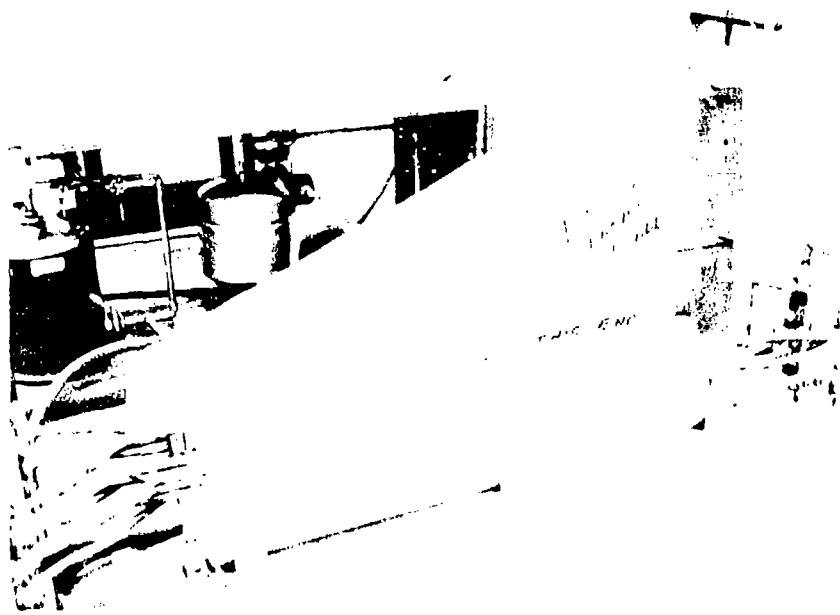


Figure 13. Blade tip section in place in prototype boot molding fixture.

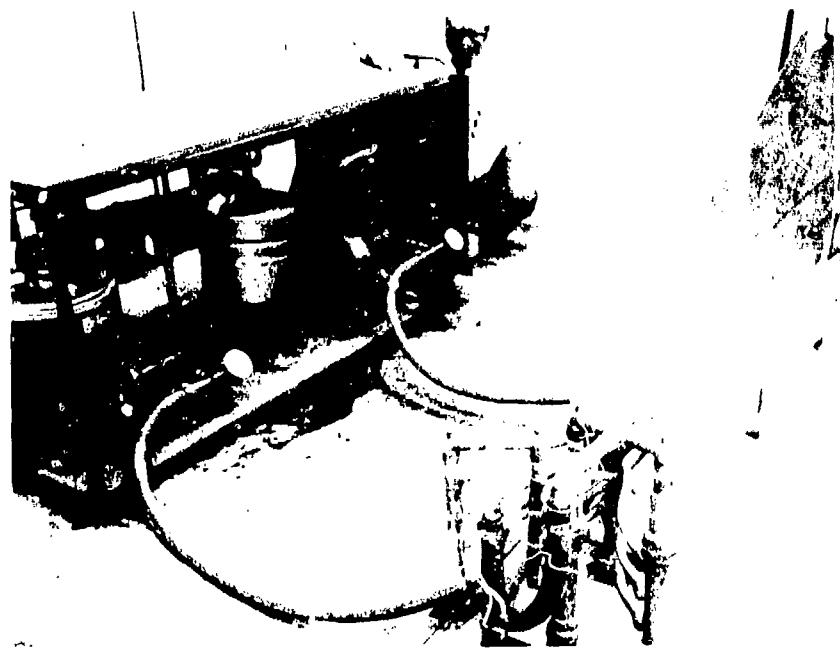


Figure 14. Blade tip section in place in prototype boot molding fixture with heating/cooling unit.

but not on the inner surface. Another crack developed in the nose at the outboard end. It was felt that the cracks would not be detrimental for the number of runs planned for this tool because the copper tubing acted as a reinforcement to hold it together.

Molding the Prototype Boot

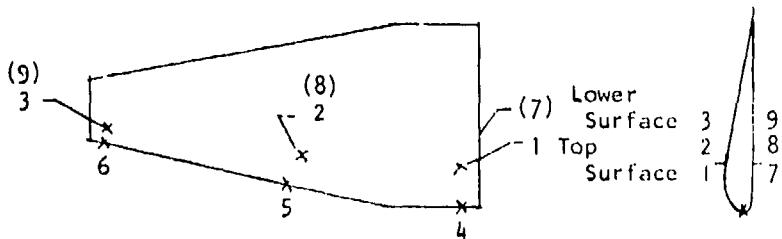
A section of scrap blade from Station 215 to the tip was obtained for this molding phase. This section was also used for heat surveys prior to any attempts to mold.

To perform the heat surveys, the section, with scrap urethane around the spar leading edge, was placed in the mold. Thermocouple wires were taped to the spar surface at strategic places to indicate heat-up rate, temperature spread, and cooling characteristics. Readings were taken at 15 minute intervals. Table 4 shows the recorded temperatures for the third survey run with scrap urethane around the nose. It is noted that the heat-up rate was slower than desired and temperatures varied somewhat at the start of the cycle, but conditions after reaching 200°F were considered satisfactory for molding.

The preliminary molding trials were started in order to develop technique and processing. From results of the prior investigations, it was determined that temperatures above 200°F would be satisfactory. The time at temperature would have to be long enough to permit the urethane to flow into position, after which it must be cooled down for solidification before removal. It was recognized at the start that air bubbles and blisters would be a major concern.

The first runs were made without adhering the boot to the spar when molding so it could be removed in one piece and examined. Figures 13 and 14 show the blade tip section in position in the molding fixture.

TABLE 4. HEAT SURVEY NO. 3



TIME MINUTES	INLET WATER TEMP (°F)	THERMOCOUPLE WIRE NUMBERS									
		1	2	3	4	5	6	7	8	9	
	Set 250°F	START CYCLE - ROOM TEMPERATURE									
15	140	90	111	98	97	118	121	121	119	103	
30	180	122	136	127	132	162	171	168	154	137	
45	220	158	161	157	167	195	203	198	179	163	
60	245	208	191	192	205	221	230	223	205	192	
75	250	235	217	213	230	237	245	242	219	213	
90	250	237	225	222	230	239	245	242	226	222	
105	250	238	229	225	241	240	245	241	230	226	
120	250	242	235	230	245	245	249	242	234	228	
COOL DOWN											
135	50	117	112	121	124	83	68	68	108	123	
150	50	93	104	97	95	63	55	55	95	94	

The first consideration before making the first run was to provide some method to indicate when the blade section was in final position for molding. This was accomplished by bonding a .10-inch-diameter soft aluminum wire around the nose on the spar surface at the inboard end at about Station 216. This was intended to act as the stop. At the outboard end, a .10-inch rubber spacer was used when it was pulled down. After being positioned, light scribe marks were made on the blade surface to be used as a double check.

After the first molding run, it was found that an insufficient amount of urethane had been used since it did not fill the cavity. For the second run, an extra strip of material was added along the nose. It was then found that the urethane was extruding outward at both ends rather than upwards along the spar surfaces. To correct this problem, an aluminum plate was cold bonded across the cavity at the outboard end. At the inboard end, the wire spacer at Station 216 was replaced by another that was bonded around the nose and up onto the spar surfaces. After the third run, it was noted that the aluminum wire was not satisfactory because the softened urethane would flow around it before the blade section bottomed out, so another aluminum plate was cold bonded across the cavity at the inboard end.

As the program continued, molding runs were made with the boot varying from a single sheet to two or more pieces cut to flat panels and laminated together, either with a heat gun or in an autoclave under heat and pressure. It was determined that the weight of the boot for the section should be approximately 1000 grams. Therefore, when making the layups, the attempt was to keep the weight between 1200 and 1300 grams. This would allow for some squeeze-out along the edges. Regardless of the layups tried, all runs showed bubbles or blisters. Figure 15 shows an early molded boot with typical surface indications.



Figure 15. Run #12 showing bubbles and surface defects.

For runs 22 and 23, the urethane was heat formed over the leading edge after which it was vacuum bagged directly to the blade. Next, the section was placed in an oven and heated to 150°F for 2 hours while still under vacuum to preheat the brass weight and withdraw trapped air. Immediately after removal from the oven it was placed in the preheated fixture and molded while still under vacuum. In run 22, the fluorocarbon release coating on the mold surface was not enough to overcome the friction between the bag and surface, and consequently the blade section could not be forced completely into position. After cool-down, the assembly was removed from the fixture and the bag was coated with silicone grease and repositioned and remolded. The resulting boot had wrinkles and indentations and was not acceptable. It was felt that preheat under vacuum did not help in overcoming the problems.

Several times, contact was made with the manufacturer to discuss the problem. It was eventually learned that the material, when made, is rolled into thin sheets which are then laminated together to obtain the desired thickness. This introduces porosity. In order to overcome this, the

preformed and tapered boot they supply to Kaman is additionally processed in an autoclave at 250°F under full vacuum and 60 psi for a period of time to eliminate the porosity and densify it.

This was done at Kaman on the material used for six of the final seven runs and did help, but did not completely eliminate the problem. When densifying, additional layers of .010-inch urethane sheets were laminated to the basic .125-inch material to obtain greater thickness. When bagging for the autoclave run, thin Teflon fabric was used on both surfaces with several layers of nylon bleeder cloth.

Figures 16 and 17 show cross sections at about 10X magnification of the material as supplied to Kaman and after the autoclave processing. The difference in porosity is readily visible.



Figure 16. Section through Estane showing typical porosity - 10X magnification.



Figure 17. Section through Estane after autoclave processing to eliminate porosity - 10X magnification.

It is noted that escaping volatiles during molding were not a problem. Laboratory testing had indicated that there are no volatiles in this material, and this is confirmed by the Goodrich engineers.

The 26th run, which was the last, had 3 brush coats of the MEK/Estane adhesive over the epoxy primer; these were oven dried at 150°F for 1 hour. A ply of 5-mil unimpregnated nylon fabric was used between the densified urethane and the spar. The layup was vacuum bagged directly to the spar before molding. The highest temperature recorded during the cycle was 213°F. Temperatures were kept low to preclude the formation of large bubbles. Pinhead bubbles were still evident although they were greatly reduced in size and number.

Peel Testing - Boot to Spar Bond Strength. Although the process had not been satisfactory at the time, it was decided to determine peel strengths obtainable using the proposed molding process as it would be on a full-length boot. This was done on run #14. It involved coating the prepared spar surface with the DAG electromagnetic shielding to the proper

resistance, over which was applied a spray coating of the epoxy primer, the same as used on the blade afterbody. This was followed by the Estane/MET adhesive tie-coat, brush applied and oven dried to eliminate solvent. It was also decided to investigate the use of an interlaminar material to facilitate boot removal but still maintain bond integrity. Consequently, a piece of .005-inch-thick nylon fabric impregnated with the urethane adhesive tie-coat was positioned around the nose under the boot between Stations 237 and 245 before molding.

Although molding results for this run were not quite satisfactory because bubbles developed, areas of the upper and lower spar surface were scribed through to provide 1-inch-wide strips for peeling back at a 180-degree angle to determine stripping strength of the bond. Figure 18 shows the method of testing with the amount of load in pounds read on the dial. Table 5 gives test results. The bond of the urethane directly to the primer was considered excellent, while the bond under the nylon fabric was considered borderline but acceptable.

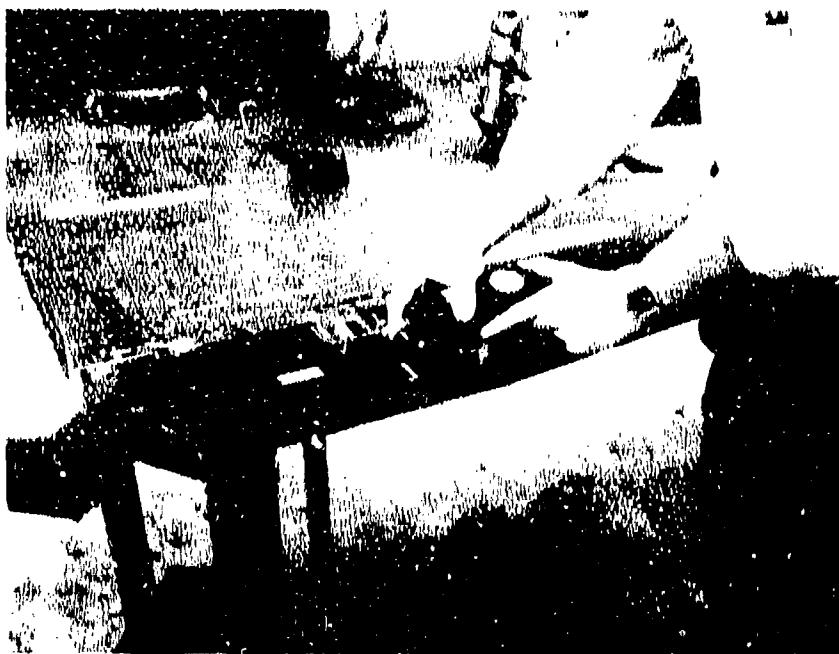


Figure 18. Method of determining the 180-degree stripping strength of the boot bond.

TABLE 5. 180-DEGREE ANGLE STRIPPING STRENGTH OF BOOT BOND

Surface	Station	Stripping Lb/In. Width	Failure
Upper	218-224	24-28	40% DAG 60% adhesive to epoxy primer
Upper	239-245	9-10	100% nylon fabric to adhesive
Upper	252-258	30-32	20% DAG to spar 80% adhesive to epoxy primer
Lower	218-224	36-39	5% DAG 95% adhesive to epoxy primer
Lower	237-246	7-8	100% nylon fabric to adhesive
Lower	237-245	27-30	100% nylon fabric to epoxy primer

At the termination of the contract, 26 molding runs had been made with molding temperatures from 205°F to 270°F. Appendix A contains a detailed breakdown of the layup for each run with significant notations. Thirteen runs were made using a single sheet of urethane and thirteen were made using multiple pieces. Included in the 26 runs were:

1. Three runs with a fine weave Teflon fabric adhered to the mold surface to permit trapped air to bleed out.
2. Four runs by vacuum bagging the blade section to the mold flanges, after the section was positioned in the fixture and before heat and pressure were applied.
3. Three runs where the boot was positioned around the leading edge under vacuum, preheated in an oven, and positioned in the preheated fixture.
4. Five runs were made by vacuum bagging the I-stane directly to the spar before positioning and heating in the mold.

Two runs were aborted. During run 3, the bolt of the turnbuckle at the outboard end of the fixture broke while pulling down. During run 19 the dam at the inboard end was forced out of position and the blade section slipped inboard due to the clamping action at the outboard end.

TASK II - TOOL DESIGN AND FABRICATION

Although the program did not progress beyond Task I, preliminary investigation was inaugurated on Task II. From the serviceability and performance of the prototype Versitool mold, it was felt that a mold made from electro-formed nickel would be superior. Sketches shown in Figure 19 were forwarded to various vendors who do this type of work. One vendor in Iowa City, Iowa had a tank long enough to fabricate this mold. A preliminary bid was received, but no further action was taken.

Figure 20 shows the original concept for the full-length production tool. This would include a box-type structure to support the nickel mold. The mold itself would have elongated attachment holes to allow for expansion when heated, and the inboard end would have an arrangement for simultaneously molding a quality control test specimen. Also planned were actuators to raise and lower the blade into position.

TASK III - FABRICATION PROCESS DEMONSTRATION

No work was done under this task.

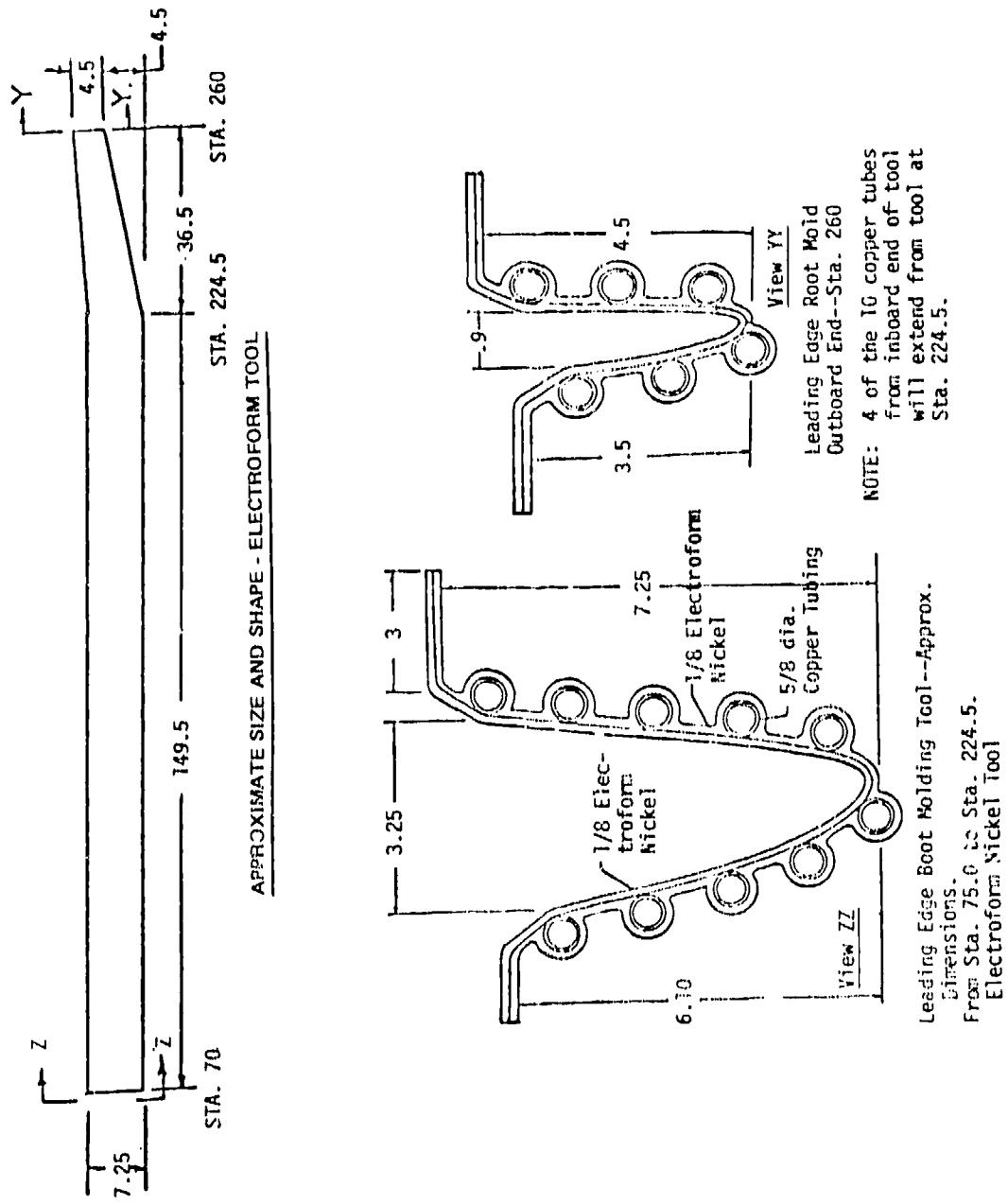


Figure 19. Proposed electroformed nickel mold.

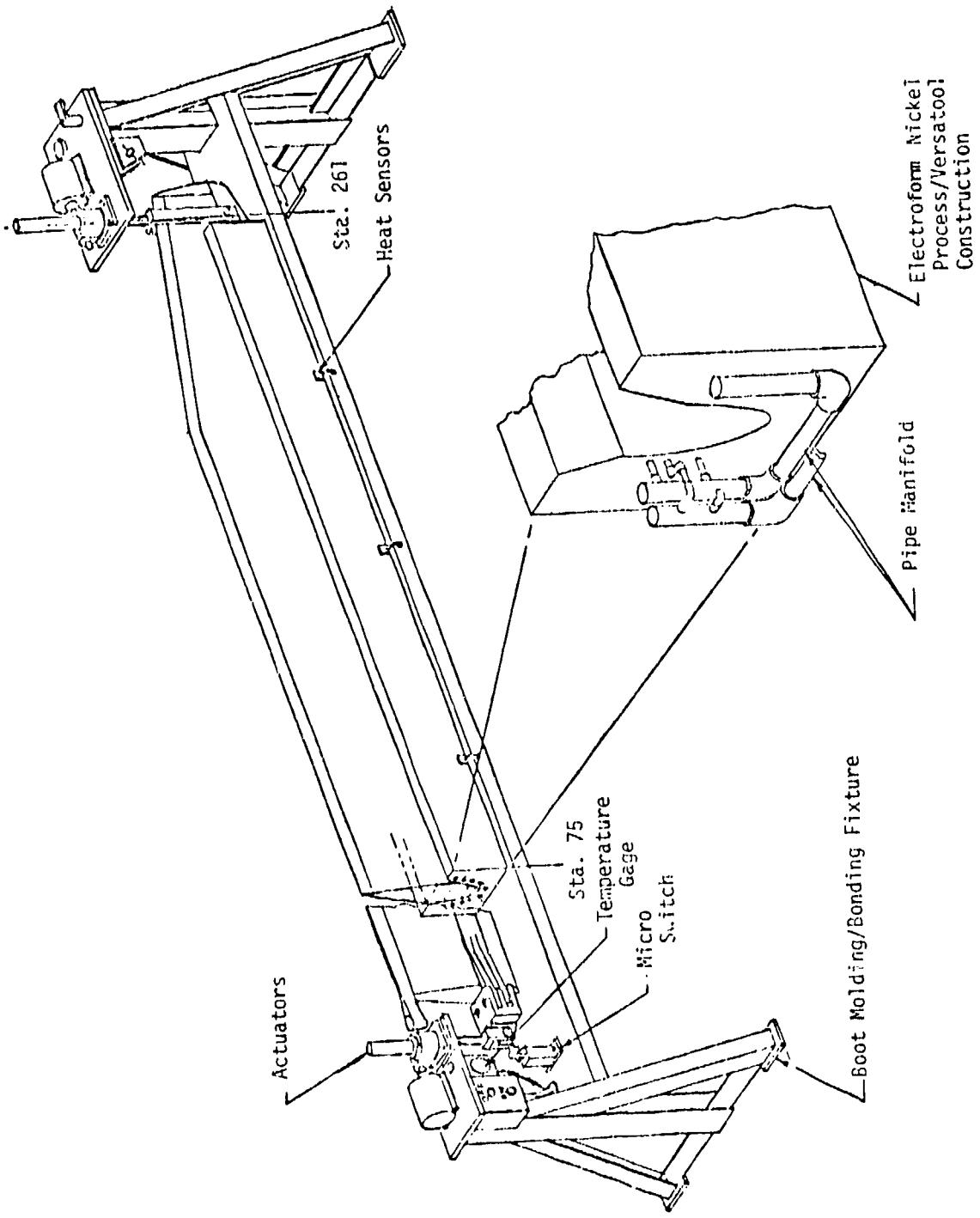


Figure 20. Tool design concept.

CONCLUSIONS

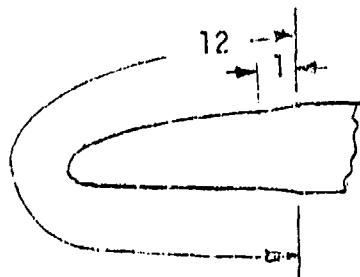
The Estane 82-083 material is very difficult to work with. An acceptable prototype boot without "pinhead" bubbles had not been fabricated after 26 molding runs under various conditions and after consultation with the Goodrich engineers.

The simple, basic process originally envisioned and demonstrated on small (\approx 3 inch long) coupon panels is not suitable for full-scale, in-place molding of leading edge guards with this material. While alternate materials and/or tooling concepts might prove satisfactory, the research and development required was beyond the scope of funding limitations of the contract.

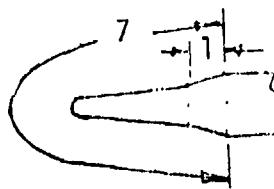
For these reasons, termination of the effort as defined by the Contract Statement of Work was recommended by Kaman, and this recommendation was accepted by the Army.

APPENDIX A
ESTANE SIZES AND LAYUP CONFIGURATIONS FOR
BOOT MOLDING RUNS

This appendix shows the various layup configurations of urethane for each run with pertinent comments.

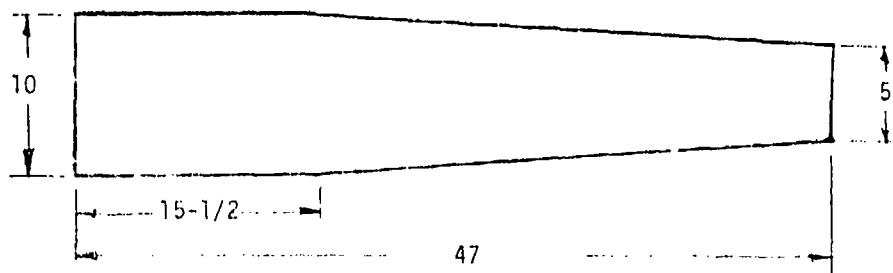


Spar Contour Inboard
Sta. 215-224.4



Spar Contour Outboard
Sta. 260

Run #1



The material was cut to a predetermined flat pattern. Weight of the piece was 980 grams. Because of the bend at Station 224, it bulged when placed in the mold so it was decided to position it on the blade section and use a heat gun to preform it in that area. Thin Teflon film was taped in place around the spar nose and silicone release paper was taped over the boot to overcome the concern that the material would adhere to the mold surface due to its extreme contour, despite surface preparation.

Figure A-1 shows the top surface after molding. It is seen that the urethane, when softened enough to flow, has no strength and follows the ripples in the paper, which was displaced slightly as the blade section was forced into position. Also noted was that some air bubbles developed and extra material was needed to completely fill the gap between blade and fixture.

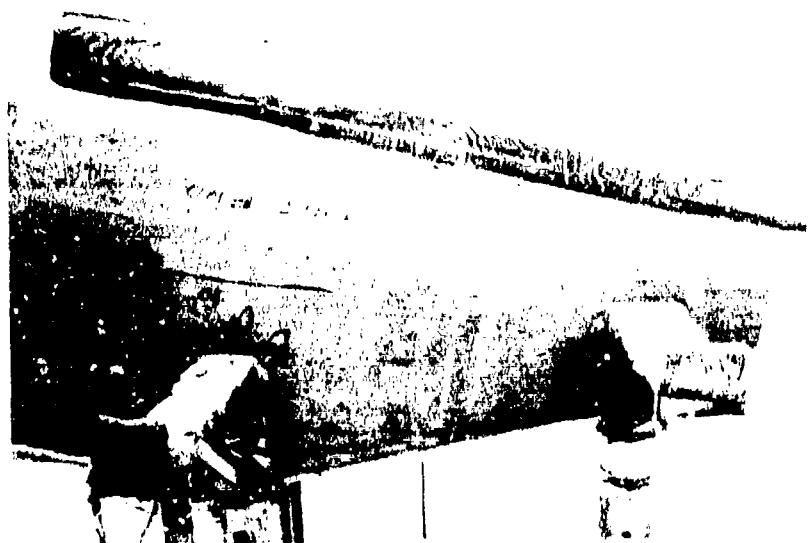
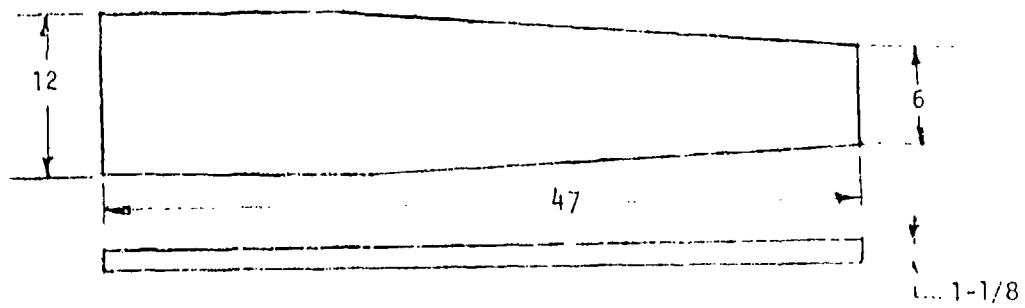


Figure A-1. Trial boot molded in first run.

Run #2



The weight of the material needed was estimated to be between 1250 and 1300 grams. This would provide sufficient squeeze-out along the feather edge to assure that the gap between mold and blade was filled. An extra piece of Estane was added to the nose. Total weight was 1289 grams. Teflon film was taped around the spar nose but no silicone paper was used between mold and boot. After cooling, the blade section was removed with the boot adhering to the mold and it had to be separated by hand. Material had not extruded up at both ends of the section, but instead it flowed out, indicating the need for dams.

Run #3

Flat pattern was the same as for run #2.

An aluminum dam was bonded at the outboard end of the fixture and a 1/8-inch aluminum wire was bonded around the nose and over top and bottom surfaces to act as spacer and dam. The material had not flowed up to the feather edge at the outboard end, and at the inboard end it was noted that a more effective dam was needed. Also, there was trapped air at the inboard end on the top surface as well as air bubbles on both surfaces. Figure A-2 shows the lower surface of the section with the air bubbles and excess squeeze-out at the inboard end. The run was aborted due to a broken turnbuckle bolt at the outboard end of the fixture.

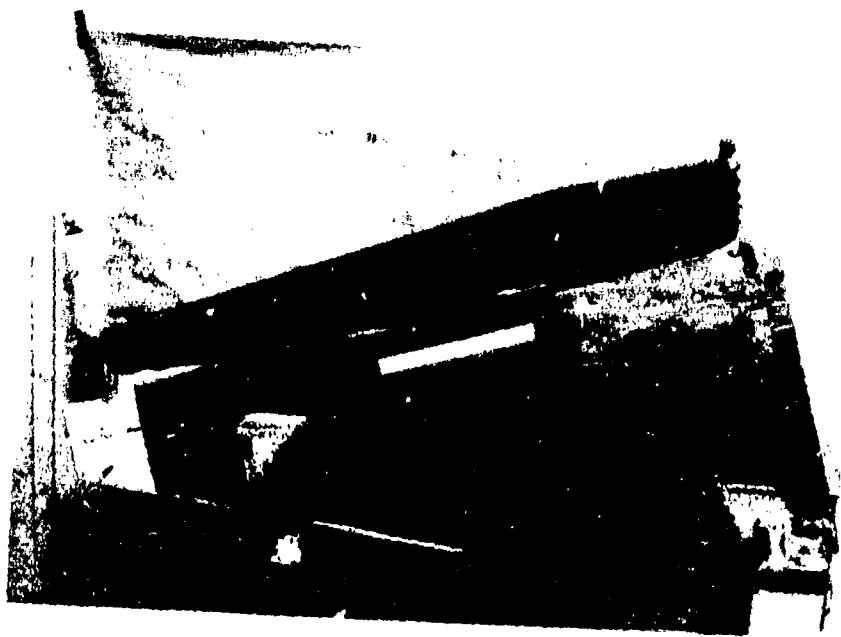
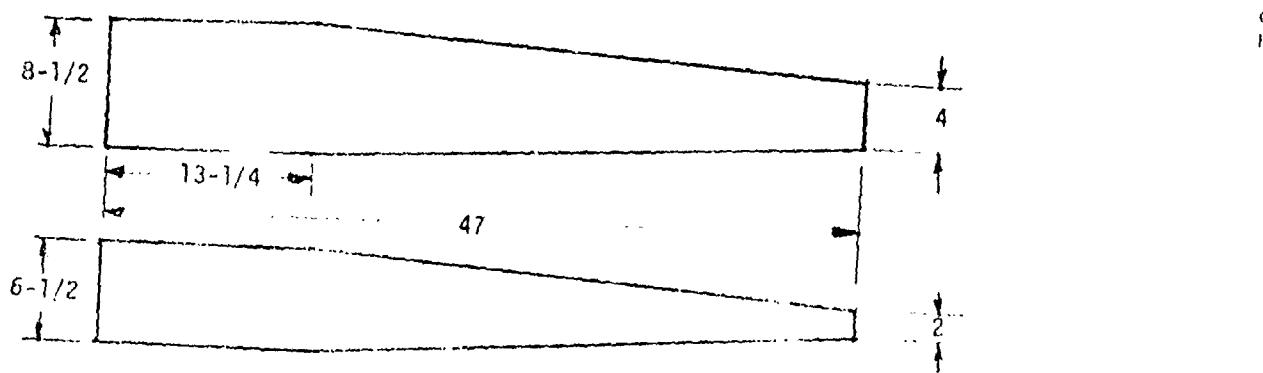


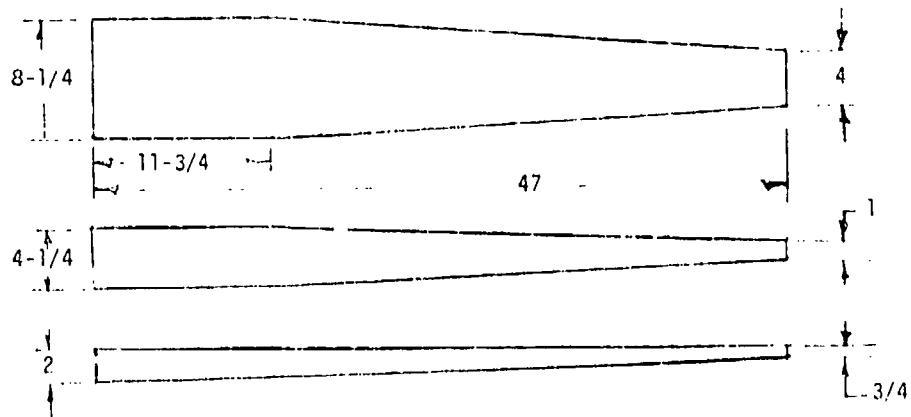
Figure A-2. Run #3 showing air bubbles and excess material squeeze-out at the inboard end.

Run #4



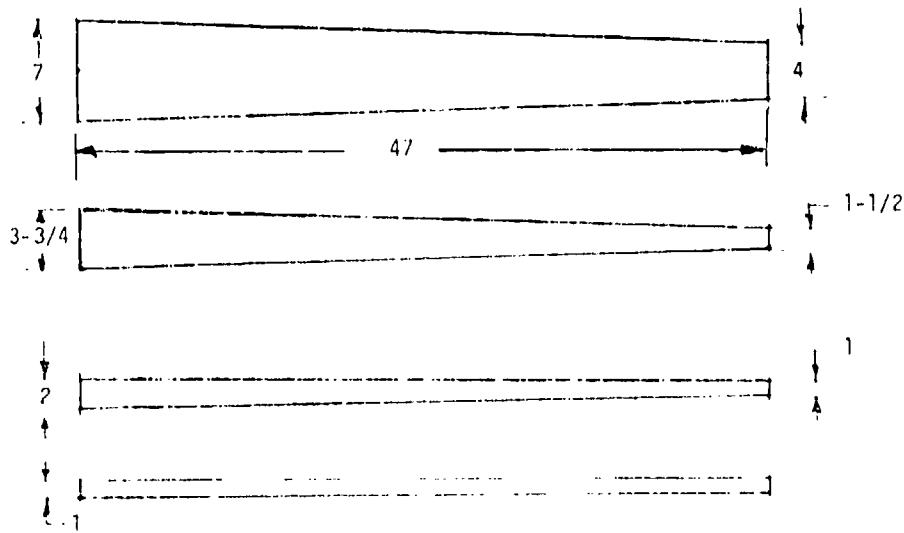
An aluminum dam was bonded across the inboard end of the cavity to direct the urethane flow upward, and the nose of the section was cut away to permit it to fit between the dams. Material flat patterns were changed but total weight was kept within the required limits. Weight of the larger piece was 767 grams and the smaller was 500 grams, making a total of 1267 grams. The pieces were tacked together with a heat gun before fitting them over the section nose. The molded part had trapped air at the ends and scattered bubbles.

Run #5



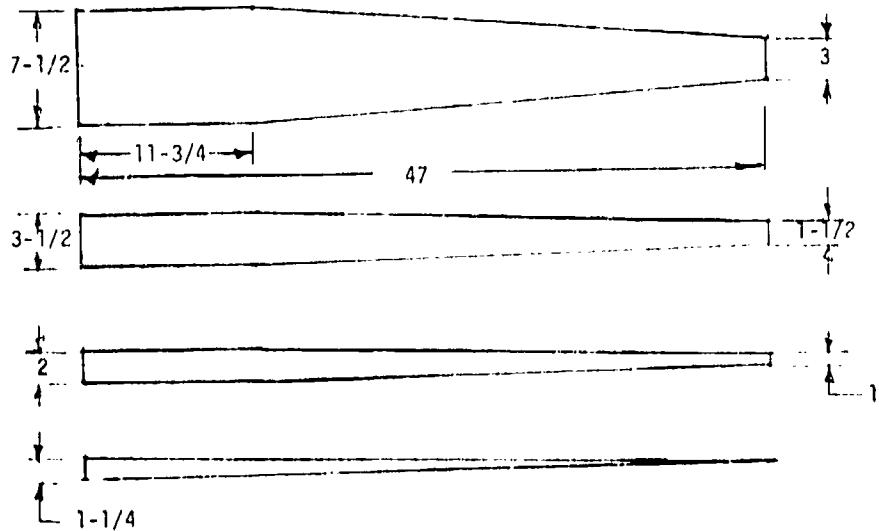
It was felt that if more material was concentrated along the nose, it would flow upward during the molding cycle, thus forcing trapped air out ahead of it. Therefore, the layup was changed to three layers having a total weight of 1282 grams. These were adhered together with a heat gun as they were laid up and formed around the nose. On both surfaces along the edge of the largest piece the urethane was tapered with a heat iron so that the section would fit lower in the mold during heat-up. The molded boot showed areas of trapped air adjacent to the mold on both surfaces as well as trapped air bubbles along the feather edge on the upper surface. Bubbles and blisters were evident on both surfaces.

Run #6



The layup was made in four layers so that more material would be in the nose to flow upward during molding. Total weight was 1273 grams. They were adhered together in the nose and the edges of the largest piece were tapered with a heat iron. The assembly was placed in a cold mold and allowed to rest until the temperature of the lowest thermocouple wire reached 215°F, after which it was gradually forced into position. It had several bubbles and dimples on both surfaces and a series of pinhead dimples along the edge of the top surface in one area.

Run #7



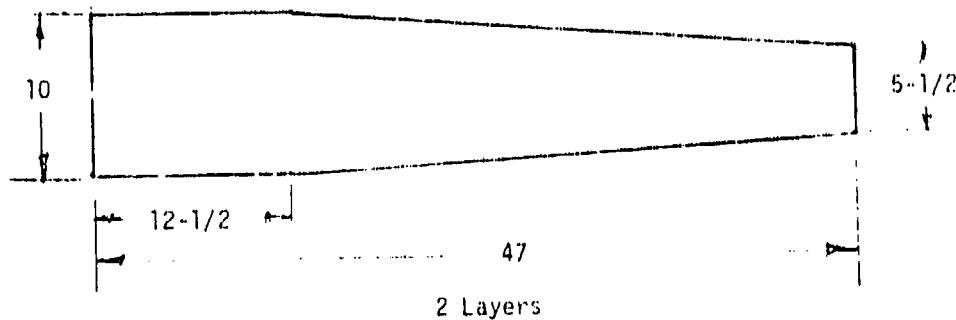
The pattern was changed slightly to put more urethane in the inboard area. The four pieces had a total weight of 1294 grams. The two largest were heat assembled as were the two smallest, after which they were formed around the spar nose and heat tacked together. The pressure relief valve of the heating unit was sticking in the open position and the highest temperature recorded was 232°F. One area on the top surface had a row of surface pits and there were several blisters on the other side. These defects were repaired as a feasibility study.

Run #8

Flat pattern was the same as for run #7.

The defective relief valve was replaced by one with a higher relief setting. The urethane pieces were assembled and formed on the spar, the same as for the previous run. It was felt that a higher molding temperature would cause the material to flow more readily and reduce bubble formation. The mold was preheated to about 200°F, and the assembly was positioned. Temperature of the lowest wire was at 234°F when the blade section was forced into position. The maximum temperature recorded during the cycle was 275°F. After removal, several bubbles were noted on either side as well as cigar-shaped areas of trapped air adjacent to the mold surface at the inboard and outboard ends.

Run #9



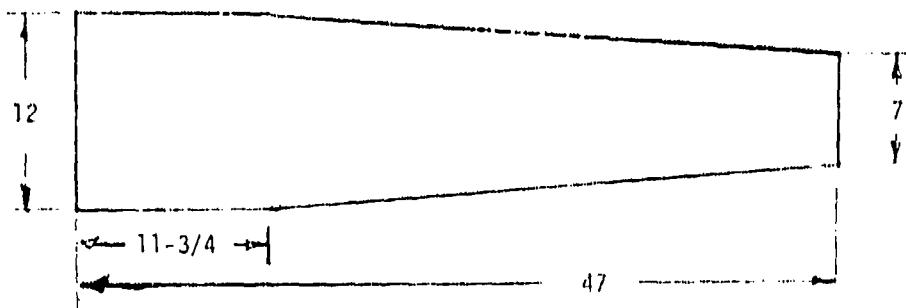
In an effort to reduce the bubbles, a different thickness of material and layup technique was used. Two layers of .08-inch-thick urethane of the pattern shown above were adhered together on a bench with a heat gun and iron to a total thickness of .16 inch. When this combination was heat formed over the spar, several interlaminar bubbles were noted. These were punctured with a scribing tool and pressed down. The assembly was placed in the cold mold and the lowest temperature noted was 235°F when the part was forced into position. The highest temperature reached during the cycle was 267°F. The molded part had trapped air between the laminations and also between the outer layer and the mold surface.

Run #10

Flat pattern was the same as for run #9.

The same .080-inch-thick urethane used for run #9 was also used for this run. Two layers of the material were cut to the same dimensions but this time they were preassembled under a vacuum blanket and fused together in an oven at 140°F for about 1-3/4 hours. Next, they were heat formed over the nose of the spar. The assembly was placed in the mold with supports used at each end to prevent it from sinking down during heat-up, thus sealing it along the edges and preventing air from escaping. When the inlet water temperature reached 225°F, the supports were removed and the part allowed to settle into position with no load applied. When the lowest thermocouple wire reached 227°F, partial load was applied and final load after the next reading with minimum wire temperature at 240°F. Maximum molding temperature on two of the wires reached 262°F. The boot had good squeeze-out along both feather edges, but several large air bubbles and blisters were also evident.

Run #11



One piece of the .125-inch urethane , which weighed 1158 grams, was used for this run. It was cut to the full 12-inch width at the inboard end and to 7 inches at the outboard end and heat formed over the nose of the section. The assembly was placed in the mold with supports at each end to keep it from settling and sealing off the air, as was done in run #10. When the inlet water temperature was at 225°F the supports were removed, and it was lowered into position. When the lowest wire reached a temperature of 240°F the load was applied to force it into position. Molding temperature was

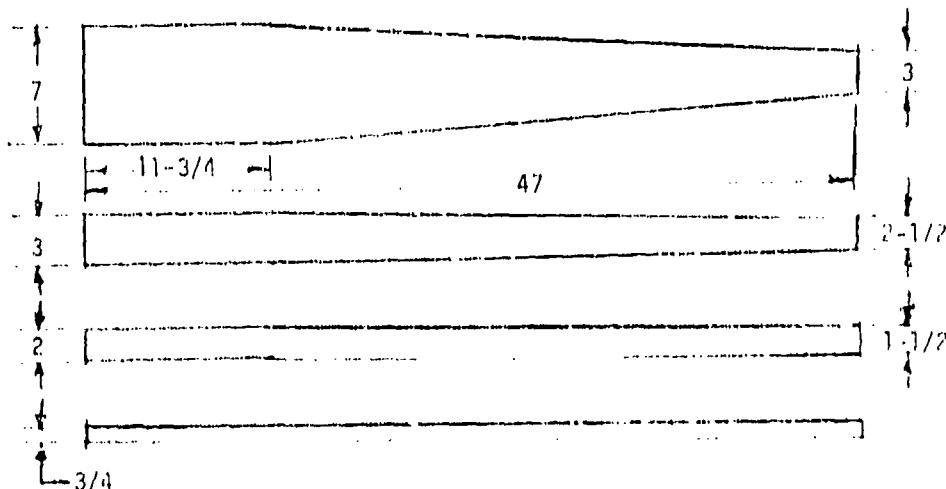
as high as 277°F on one wire. Urethane squeeze-out was seen all along the edges on top and bottom surfaces. The formed boot had numerous bubbles and blisters on each side, ranging from 1/8 to 1-1/2 inches in diameter, as well as a trapped air pattern between boot and mold at the inboard end, top surface. Surface pits were also present on both sides in the Station 240-250 area.

Run #12

Flat pattern was the same as for run #11.

This run was made with the same thickness and size material as the previous one. The weight was 1130 grams. It was felt that a vacuum would be helpful in eliminating the trapped air. The mold was lined with thin pressure-sensitive Teflon fabric to assist in bleed-out. The assembly was placed in position in the mold and a vacuum blanket was used to seal the blade section to the mold cavity along both sides and the ends. A vacuum port was placed at each end, and it was possible to draw a vacuum of 21 inches of mercury. When the lowest wire showed a temperature of 208°F, the assembly was gradually forced into place. The molding temperature reached as high as 261°F. Urethane squeeze-out was seen all along both edges, but the formed boot had bubbles on both sides and surface pitting on both sides at the trailing edge in the Station 240-250 area.

Run #13



This run was made under the same vacuum conditions as run #12. The mold had the Teflon fabric liner adhered to its surface and vacuum was drawn with a hose at each end. The basic difference was that the previous run was made with one full size piece of urethane, while in this run four pieces were used with the largest piece being only 7 inches wide. Total weight was 1237 grams. The reason for the multiple pieces was to permit the assembly to fit deeper into the mold cavity and reduce trapping of air as the urethane flowed into position on the spar. Lowest thermocouple wire temperature was 210°F when the part was gradually forced into position and the highest temperature recorded during the cycle was 251°F. The part had fewer bubbles but this plus other defects made it unacceptable.

Run #14

Flat pattern same as for run #13.

This run was made with vacuum, Teflon liner, and 4 pieces of urethane essentially the same size as for run #13. In this case, more vacuum lines were used with more effective air bleeders along the length of the mold. Two vacuum lines were used at each end, one on either side of the assembly, and one in the nose. The spar surface was prepared and processed with the DAG/epoxy primer and adhesive just as it would be for a production run.

To investigate a method for removal of the boot so as to damage the DAG/epoxy coating as little as possible, a piece of nylon fabric, .005 inch in thickness, was laid around the spar nose from Stations 237 to 245 under the urethane before molding. The material received a brush coat of Estane/MEK tie-coat on both sides and then was air dried and oven dried. During this molding run, the highest temperature reached on any one thermocouple wire was 235°F. The molded boot had some trapped air and other defects which made it unacceptable, but the peel strength of the good portions was determined as a matter of record. They are reported in Table 5 of this report.

It is noted that when removing the boot from the spar, the bond was so strong that the epoxy coating in some areas was raised with it, with failure occurring in the DAG. In the area of the nylon fabric this did not occur, and the peel strength was not as high as desired.

Run #15

Flat pattern was the same as runs #13 and #14.

For this run, the Teflon liner and vacuum blanket were not used because it was felt that they did not help. It was made using the same number and sizes of urethane pieces as run #14. The two largest pieces were adhered together; the remaining two were also joined, using a heat gun. The spar surface was cleaned and given a brush coat of the urethane adhesive. When forming and tacking the material to the spar, the edges of all layers were heated and tapered so that they would blend and join together more smoothly. Molding temperature was kept in the low range to try to reduce formation of bubbles. Lowest recorded temperature was 200°F when the assembly was forced into position and the highest recorded temperature just before the end of the cycle was 230°F. This boot was not acceptable because of small scattered bubbles and surface indications.

Run #16

Flat pattern was the same as for run #9.

For this run, a single sheet of the .125-inch urethane was used. The spar was cleaned and given a brush coat of Estane/MEK, and the sheet was heat formed and tacked around the nose. It was placed in the cold mold. The object was to let it sit until molding temperatures had stabilized at a minimum to keep potential air bubbles as small as possible. After 1-3/4 hours, mold temperatures stabilized, ranging between 199°F and 204°F, and the specimen was forced into position. Maximum temperature recorded on any wire during the cycle was 213°F.

The molded boot had bubbles and surface porosity on both surfaces and a cigar-shaped void on the upper surface along the nose going from Stations 235 to 240. This could have been the result of resting for too long a period in the mold as it was heating up, before being forced into place.

Run #17

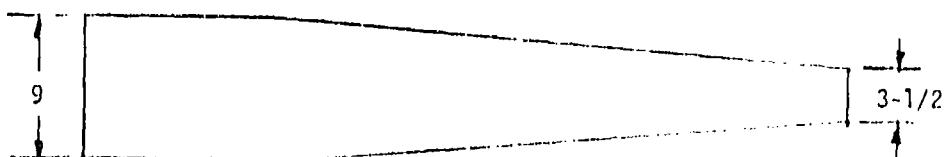
Flat pattern same as for run #9.

This run was also made with one single sheet of the .125-inch-thick urethane. The flat pattern was almost the same as for run #16. The slight differences were made to control squeeze-out. The mold was preheated for 1 hour with the inlet water temperature set for 200°F, then the assembly was placed in the mold and gradually forced into place immediately after positioning. It was in its final position in 15 minutes. Maximum temperature on the highest thermocouple wire was 214°F. The molded boot had some bubbles and surface porosity on both sides.

Run #18

7
B

(2 pieces Goodrich Production Boot .10" Thick)

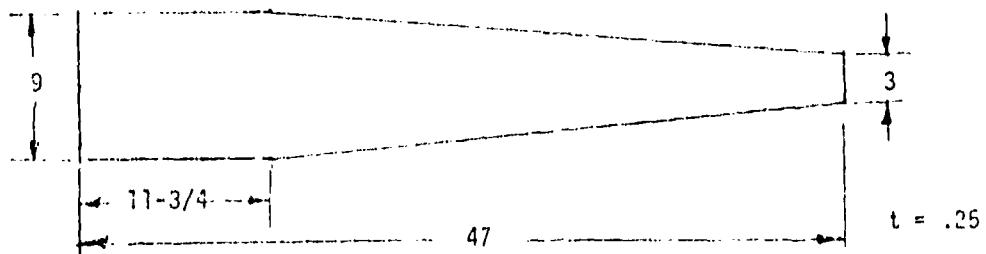


This run was made in an effort to determine how the porosity of the urethane affected the molded boot. A scrap production Goodrich boot was used. Because this material is only .10 inch in thickness, and greater thickness is desired to start, it was necessary to use 2 pieces, both cut to the same flat pattern and fused together with heat gun and metal roller. Total weight was 1229 grams. The spar surface was brush coated with the Estane/MEK adhesive and the urethane was heat formed and tacked to the nose. The mold was allowed to preheat for 1-1/4 hours and water inlet temperature was

195° - 200° F when the assembly was positioned. The assembly was very gradually forced into place starting immediately after positioning and was thought to be in place by the end of the first 1/2 hour. When forcing it into position, it was noted that the mold was bulging at the crack in the flange on the lower surface. After the thermocouple wire in the area reached 190° F the bulge reduced back to normal. The part was held at temperature for 15 minutes after the lowest wire reached 197° F with maximum temperature reaching 206° F.

After removal, it was found that the part had not been completely into position as thought, resulting in thick urethane in some areas, very little squeeze-out, and some small bubbles and surface defects. The assembly was rerun by placing it in the cold mold, heating to 200° F, and then forcing it into place gradually. This time, molding temperatures were in the 240° F range. The resulting part appeared fairly good, being more nearly to contour and showing better squeeze-out along both sides, but most of the bubbles and defects still remained.

Run #19

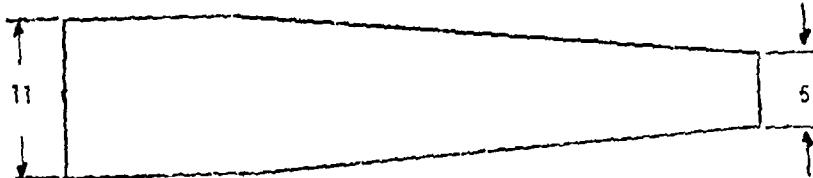


The densifying technique to eliminate the porosity in the urethane, which was mentioned earlier in this report, was started with this run. It was felt that one layer of the .125-inch urethane would not be thick enough, so for this run two layers were laminated and densified together in the autoclave, after which they were cut to the pattern. The material was heat formed over the nose of the tip section and the assembly was

placed in the preheated mold. The highest recorded molding temperature was 224°F.

While tightening the outboard clamp to pull the assembly down in the fixture, the dam at the inboard end, which also acts as a stop, broke away and the assembly moved inboard making it impossible to reposition the clamp, so the run was aborted.

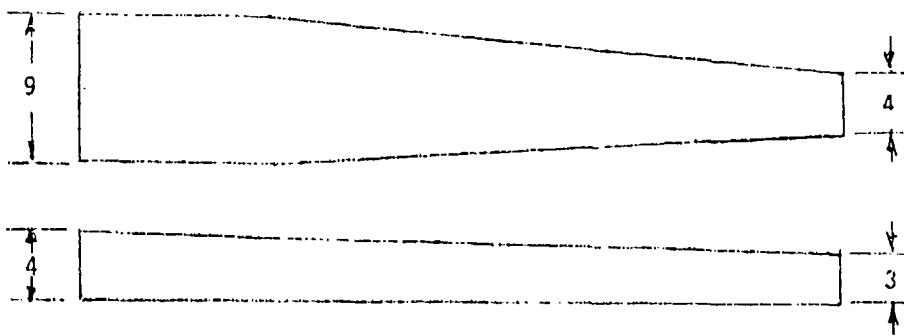
RUN #20



For this run, in order to obtain a thicker urethane sheet, 4 pieces of .009-.010-inch-thick sheet were laminated with 1 piece of the .125-inch urethane and densified together, resulting in a thickness of .150-.160 inch and a weight of 1218 grams. The urethane was formed on the nose of the tip section and placed in the cold mold. When the lowest thermocouple wire reached 200°F, the assembly was gradually forced into position for molding. The outboard clamp slipped off while forcing the assembly into position, but it was immediately replaced. The assembly had moved about 1/16 inch inboard. Maximum temperature reached was 226°F.

The molded part had bubbles and surface indications which made it unacceptable.

Run #21



This run was made with two different size pieces of the .125-inch urethane, cut to flat pattern and laminated together and densified. Densifying the flat pattern resulted in the edges being slightly tapered to achieve a better fit into the mold. It was then formed and vacuum bagged to the nose of the section and then placed in an oven at 150°F for 1 hour to draw trapped air from under the boot. It was taken from the oven, the vacuum bag was removed, the assembly was positioned in the mold, and then it was vacuum bagged to the mold itself. This vacuum was held throughout the heat up and the molding run. Highest temperature recorded was 227°F.

This boot was better than most of the previous boots molded, but a row of small blisters from Station 240 to 250 along with some other scattered defects made it unacceptable.

Run #22

Flat pattern same as for run #20.

For this run, it was decided to do everything possible to eliminate the bubbles, even to the extent of vacuum bagging the urethane to the blade section and maintaining the vacuum during the molding cycle. The material was densified with the same flat pattern as for run #20. After this, it was formed over the nose of the spar and a ply of thin Teflon fabric was used as a bleeder between the surface and vacuum bag. It was then placed in the oven under the vacuum for 2 hours at 150°F in order to preheat the brass

weight. Next, it was removed and immediately placed in the mold, which had also been preheated for 2 hours with inlet water temperature at 225°F. After the first 15 minutes of heat-up, the temperature range was 178°-211°F. The assembly was loaded gradually to force it into position and was in approximate final position after 1/2 hour heat-up with the temperature range of 194°-218°F. The highest recorded temperature for this cycle was 224°F.

When forcing the section into position, it was noted that more force had to be applied to move it into position. This was later felt to be caused by the material not being quite soft enough, the drag of the urethane flowing against the weave of the Teflon fabric, and the drag of the vacuum bag against the mold surface which had only the fluorocarbon spray coat.

The molded boot was free of blisters and bubbles, but bag wrinkles and occasional depressions were evident. Also, the surface texture resulting from the fabric weave was not desirable. It was also noted that the assembly had not quite bottomed out in the fixture, so it was replaced and recycled, but the boot appearance did not improve.

Run #23

Flat pattern same as for run #11.

The feeling was that vacuum bagging directly to the spar was the most promising of the techniques tried this far. This run was made to experiment with the process so that a minimum of effort would be used to form a boot. The intent was to densify the urethane while it was being molded under the vacuum bag. Also, extra attention would be given to the vacuum bag to keep wrinkles to a minimum and the external surface would be lubricated. One layer of the basic .125-inch-thick urethane was used without autoclave processing to densify it. No adhesive was used on the spar. The vacuum blanket and mold surface were given a coat of silicone grease and the assembly, under vacuum, was exposed to 150°F temperature in the oven for 2 hours to preheat the brass tip weight. The mold was preheated to

225°F prior to the molding cycle. When the lowest temperature noted was at 191°F, it was gradually forced into position. Highest temperature reached was 204°F. The molded boot was free from wrinkles but some small size bubbles were noted in various places on both sides, apparently the result of the porosity. In appearance, this boot was among the best molded.

Run #24

Flat pattern was same as for run #11.

Because of the small size bubbles formed in the previous run, it was felt that material densified in the autoclave would give better results. Two layers of the .010-inch urethane were added to the .125-inch sheet, and they were densified in the autoclave. No adhesive or integral bleeder was used between boot and spar surface, but the thin Teflon film was again tried between boot and vacuum bag at the inboard end between Stations 215 and 222. The assembly was processed the same as for run #23. Highest temperature recorded was 208°F.

The surface of the molded boot had a good appearance except in the area where the Teflon fabric was used. Also, in that area there were no bubbles or blisters, but the weave of the fabric apparently inhibited the flow of the urethane, and the force necessary to push it into position caused the boot to get thin along the nose. The remainder of both surfaces to station 260 looked good, but again, there were scattered small bubbles within the boot material.

Run #25

Flat pattern same as for run #11.

For this run, one layer of the densified urethane was used with an average thickness of about .145 inch. The flat pattern was the same as for runs #23 and #24, made during the previous period. The weight was 1558 grams, which is about 300 grams more than the amount normally used for molding the

section. One ply of nylon fabric bleeder was laid up between the spar and boot. During the run, the bolt retaining the clevis for pulling the out-board end of the specimen failed before final seating. The part was cooled and the bolt replaced. The assembly, still under vacuum, was replaced in the mold and recycled. The finished boot still had "pin-head" bubbles even with the nylon bleeder and was also thinned out along the nose. This was caused by the drag of the vacuum bag along the sides of the mold although they had been recoated with silicone grease. The dragging was attributed to the fact that there was too much urethane to be moved out beyond the feather edges after being softened.

Run #26

Flat pattern slightly smaller than for run #11.

In this run, the average thickness of the densified urethane was approximately .130 inch. The flat pattern was cut slightly smaller than for run #11 with the weight of the piece to be molded at 1271 grams. The spar surface was prepared and given a spray coat of epoxy primer without the undercoating of the DAG 502 electromagnetic shielding. Three heavy brush coats of the 20% solids Estane/MEK adhesive were applied to the spar and one ply of nylon fabric was used between the urethane and the spar surface. The urethane sheet was vacuum bagged directly to the blade section, which was then placed in the mold. Highest temperature recorded during the molding cycle was 213° F.

For appearance, this was considered to be the best boot molded. However, scattered pinhead bubbles were still evident on both surfaces. Three 180-degree peel specimens were taken from each surface to observe the effect of the nylon bleeder between the boot and spar. Peel strengths were low, being in the range of 5 to 7 pounds per inch of width with 80-95% failure of nylon to adhesive.

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